Deep Impact: ACS Fault Tolerance in a Comet Critical Encounter*

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***Keywords**: Fault Protection, Fault Tolerance, Redundancy, ACS, Deep Impact, Planetary Spacecraft*

The Deep Impact Project is a NASA Discovery mission to explore cometary science. A mother-daughter dual spacecraft, the Flyby and the Impactor, will launch in January 2004 to intercept comet Tempel-1 on July 4, 2005, as Tempel-1 swings around the Earth and the Sun in its 5.5-year heliocentric orbit.

The Impactor will separate from the Flyby twenty-four hours before closest approach to Tempel-1. The Impactor will be aided by on-board auto-navigation as well as Flyby auto-navigation updates, and should impact the comet at a speed of 10.2 km/s., creating a crater of the size of a football field. Science observations will be conducted during Impactor free flight. The Flyby, after separation, will execute a divert maneuver, perform auto-navigation, send estimated time-of-impact updates to the Impactor, and perform science observations of the formation of the crater and ejecta produced by the impact. Sixteen minutes after the impact, the Flyby will brace itself for the crossing of the intense dust tail of the comet, a crossing that takes about 5 minutes. Science and engineering data, from both the Flyby and Impactor (relayed via an Impactor-to-Flyby S-band, prior to impact) will be transmitted to the Deep Space Network (DSN) before and after the comet tail crossing. The Deep Impact mission ends twenty-eight days after comet crossing.

The near comet environment is particularly hazardous and poses a strong challenge for spacecraft and navigation design. In the absence of prior detailed observation, comet Tempel-1 is an uncertain, tiny, optical target. Jets, diffuse visibility, low and varying albedo, and non-uniform spectral features pose large uncertainties to optical navigation. In addition, dust impingement on spacecraft is almost certain during comet tail crossing, where impingement will torque or even tumble the spacecraft. Damage to spacecraft shield, bus, and other hardware is not unlikely.

The above mission objective and encounter scenario requires a fault tolerant and autonomously recovering design for both spacecraft. Hardware redundancy and functional redundancy are designed into the Flyby, and to some extent, the Impactor. The spacecraft Flight Software (FSW) implements a Fault Protection (FP) software architecture that centralizes the detection and recovery of internal and environmentally induced faults.

FP software is resident in each FSW application, monitoring the operation of each and every hardware subsystem. FP Monitors detect threshold violations and raise Symptom notifications for persistent violations within different "fault containment regions". Threshold violations trigger immediate Local Responses within the applications, while Symptoms trigger System Level Responses that coordinate spacecraft-wide recovery actions.

Necessitated by the environmental demands of the Encounter mission scenario, the Attitude Determination and Control Subsystem (ADCS) has adopted a robust, redundant, and fault tolerant design, in hardware as well as in software, where FP serves as the oversight agent. The 24-hour operation prior to impact, the intense science observations prior to comet tail crossing, and the attitude control during crossing and after crossing are "Critical Sequence" activities. A majority of mission objectives are to be achieved during this short time period, and do not afford much ground intervention if a fault occurs.

This paper describes the overall FP architecture and design on the Flyby and Impactor. Specifically, the ADCS FP design will be addressed. The extra functionality required of the Deep Impact mission will be highlighted against FP designs of other planetary spacecrafts, such as Cassini and Deep Space 1 (DS-1).

This work was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA, under contract (NAS701407 task order 10389) to the National Aeronautics and Space Administration (NASA). Ball Aerospace Technology Corporation, Boulder, CO, is the System Contractor for the Deep Impact Project.